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Off the Rails: The Cost Performance of Rail Projects

Abstract: Governments in Australia place great emphasis on the development and expansion of their rail networks to improve productivity and service the increasing needs and demands from businesses and commuters. A case study approach is used to analyze the cost performance of 16 rail projects constructed by a contractor between 2011 and 2014, which ranged from AU$3.4 to AU$353 million. Findings indicate that scope changes during construction were the key contributors that lead to the amendment of each project's original contractual value. As a result, there is a need for public and private sector asset owners to establish a cost contingency using a probabilistic rather than a deterministic approach to accommodate the potential for scope changes during construction. To improve cost certainty during the construction of rail projects, it is suggested that use of collaborative forms of procurement juxtaposed with the use of Building Information Modelling and Systems Information Modelling are implemented. The utilization of such technological and process innovations can provide public and private sector asset owners charged with delivering and maintaining their rail networks with confidence projects can be delivered within budget and are resilient to unexpected events and adaptable to changing needs, uses or capacities.

Keywords: Australia, BIM, collaboration, contingency, cost overrun, scope changes, SIM

Introduction

Investment in rail infrastructure is critical for improving the Australian economy's productivity and competiveness. The Federal and State Governments have placed great emphasis on the development and expansion of their urban, non-urban and freight rail networks (Infrastructure Australia, 2016); in doing so, it may require the construction of new stations and tracks, extensions to existing lines, electrification of suburban networks, amplification and line upgrades and maintenance. It is, therefore, necessary that existing rail infrastructure is maintained to the highest standards and upgrades and new projects are completed on schedule so as not to adversely impact businesses and commuters. There is however a propensity for rail projects, irrespective of their size (i.e. in terms of contract value) in Australia to experience cost overruns

(Terrill and Dankes, 2016). Moreover, 'large' urban rail projects (i.e. in excess of AU$500 billion) such as the Gold Coast light rail, Moreton bay rail link, Sydney light rail and the Perth-Mandurah rail line have experienced significant cost overruns; the multitude of interdependent components and interfaces that exist when integrating infrastructure amplify the likelihood of cost overruns occurring (Terrill and Dankes, 2016).

Evidence indicates that the problem of cost overruns is a worldwide phenomenon for rail infrastructure projects (e.g., Leavitt *et al*., 1993; Flyvbjerg *et al*., 2007; Canteralli *et al*., 2012a,b,c). For example, in the United Kingdom (UK) the Edinburgh Tram System experienced a cost overrun in excess of 100%. In the United States (US), for example, several high profile rail projects have experienced significant overruns, namely (Grabauskas, 2015): the US$1.8 billion central link light-rail project in Seattle was 38% over budget; Phoenix's US$1.07 billion East Valley light-rail project was 31% budget; San Francisco's US$1.2 billion airport heavy-rail project, 30% over budget; and Los Angeles' US$3 billion heavy-rail red line project, 47% over budget. These cases reiterate a never ending story for taxpayers; shortfalls in construction costs result in increased debt and thus increases in taxes, which can often span generations to repay the borrowed monies of government. This situation has become clearly the case in Honolulu rail transit project that commenced in 2008, which was expected to cost US$4 billion to construct (Mangieri, 2016) and is expected to exceed US$10 billion upon completion (Daysog, 2016).

A major contributor of construction cost increases that have been experienced in the Honolulu rail transit project has been the limited supply of labor and the increasing cost of materials (Shimogawa, 2016). When preparing the budget estimate for project, forecasting the supply and demand of labor and materials is an arduous task, and in some instances may be impossible to determine, especially when estimators have to calculate construction costs months or even years in advance; in this instance 'uncertainty' prevails and 'guesstimating' occurs (Sing *et al*., 2012a; Sing *et al.*, 2012b). In the case of the Sydney light rail project, for example, under estimation of the cost of moving utilities such as power cables significantly contributed to increased construction costs (Saulwick, 2014); this also occurred during the Edinburgh Tram System. Importantly, 'as-built' documentation for power cables seldom exist and if they do or they are often inaccurate (Love *et al*., 2016a). With different cities being characteristically unique (i.e. in terms of their history, layout and structures), it is unrealistic to assume that an accurate forecast of the location of underground utilities can be undertaken. A ‘provisional sum’ (i.e. an allowance for undefined work), is therefore, typically provided when this situation arises (Smith *et al*., 2016). A design contingency (i.e. allocated for changes during design for factors such as incomplete scope definition and estimating inaccuracy) is required and subsequently reduced as more information becomes available. Prior to the commencement of construction, a contingency (i.e. where any unresolved design issues at the time of contract award are incorporated into the estimate/contract price) is also needed, though this often calculated deterministically rather using a probabilistic approach (Baccarini and Love, 2014; Love *et al*., 2015a; Love *et al*., 2016b).

Research undertaken by Flyvbjerg (2007) and Canteralli *et al*. (2012c), for example, have provided an initial platform for understanding cost overruns in rail projects, particularly those classified as being ‘mega’ (i.e. in excess of $1 billion), in their size and complexity. Issues surrounding strategic misrepresentation, optimum bias and political machinations abounding have been over-emphasized in the planning and transport literature (e.g., Siemiatycki, 2009), with much of the research propagated being incorporeal (e.g., Love *et al*., 2012a; Osland and Strand 2015). Explanations of this nature, however, have attracted the interest of the media and when appropriate to opposition political parties and undoubtedly served as a point of reference to begin to understand why mega rail projects experience cost overruns (Flyvbjerg, 2007; Terrill and Dankes, 2016).

Rather than focusing on ‘large’ and ‘mega’ projects, which have tended to be the focus of previous research studies in this area, an exploratory case study approach is used to analyze the cost performance of a combination of public and private sector rail projects constructed by a contractor between 2011 and 2014, which ranged from AU$3.4 to AU$353 million. While the public and private sector asset owners are diverse, the processes, procedures and technologies used by the contractor for rail projects were identical in nature. The research that is presented provides a much needed context to further explain the nature of cost overruns and how to mitigate their occurrence.

Cost Overruns and Rail Projects

Two schools of thought have evolved to explain the nature of cost overruns in the transportation literature, these being the 'Evolutionist' and 'Psycho Strategists' (Love *et al*., 2016). Each approach provides a platform to recognize the extent and issues contributing to the cost overrun problem, but they are unable to provide a robust and balanced causal explanation of this phenomena. Considering the absence of a theory of cost overrun causation, Love *et al*. (2016) have suggested that a pluralistic probabilistic approach is required to accommodate the interdependencies that exist between causes so as to provide public and private sector asset owners with a holistic understanding of the uncertainties and risks that may derail the delivery and increase the cost of their transportation projects.

While there have been a significant amount of studies that have examined cost overruns in road projects (e.g. Bordat *et al*. 2004; Odeck, 2004; Vidalis and Najafi, 2004; Liu *et al*., 2010; Canteralli *et al*., 2012a,b,c; Love *et al*., 2015a; Odeck *et al*., 2015; Verweji *et al*., 2016a; Terrill and Dankes, 2016), the number that have focused on rail projects has been limited (e.g., Pickrell, 1990; Fourace *et al*., 1990; Leavitt *et al*., 1993; Dantata *et al*., 2006; Flyvbjerg *et al*., 2007); more research is needed to understand the dynamics and nuances of rail projects so as to contribute to the development of a theory of cost overrun causation.

The sample size of rail projects that have been examined has been small, ranging from as low as 10 (Pickrell) to a maximum of 169 (Canteralli *et al*., 2012c). According to Flyvbjerg (2007) rail tends to experience the largest cost overrun of all the types of transportation projects with a mean of 44.7%. The reported mean cost overruns, however, differs significantly between studies in various countries; ranging, for example, 50% in the US (Pickrell, 1990), 10.6% in the Netherlands (Canteralli *et al*., 2012c), and 17% in Sweden (Lundberg *et al*., 2011). A primary reason for this observed disparity between studies is the 'point of reference' from where the cost overrun is measured (Love *et al*., 2015a; Love *et al*., 2016a). Within the planning and transport fraternity, the difference between initial forecasted budget and actual construction costs is typically used to calculate cost overruns (Canteralli *et al*., 2012a). Between the initial forecasted budget of construction costs and the commencement of construction, several estimates will be prepared and refined before being lodged for approval.

Odeck (2004) has suggested that the reference point for determining a cost overrun should be at the detailed planning stage where design, specification and final cost are determined. Conversely, Love *et al*. (2015a) advocated that cost overruns should be determined at the point where a contract has been signed to perform the construction works. However, research undertaken by Terrill and Dankes (2016) has revealed that the timing of cost overruns occurs at different stages for transport projects. In the case of roads, for example cost overruns are larger during the planning stage as they tend to be bespoke. According to the Parliament of New South Wales (2012), rail projects tend to be homogenous during their planning stage, as many key components are standardized and can be purchased at a known price. Problems tend to occur in rail projects during construction, as they are generally built on brownfield sites, and need to be integrated with existing infrastructure and on-going operations; the magnitude of the cost overruns occurring during their construction has been revealed to be significantly higher than that of road projects (Terrill and Dankes, 2016). The findings reported in Terrill and Dankes (2016) reiterates the need to have in place an adequate contingency that can accommodate changes that arise during construction and therefore provide an improved degree of cost certainty. This will depend upon the procurement method that is adopted and the completeness of the tender documentation provided to the party/parties (i.e. contractor/consortium/joint venture) contracted to perform the required works.

A significant omission by Flyvbjerg (2007) and Canteralli *et al*. (2012a,b,c) is that they have not fully acknowledged the influence that a procurement method and contract can have on a project's costs. For example, if a rail project is to be delivered as an alliance contract, then a consortium can be 'locked-in' by the contract to provide a Guaranteed Maximum Price (GMP) based on an initial budget estimate. Using procurement methods of this ilk can be used to transfer 'design' and 'construction' risks to a single entity. In addition, if a Public-Private Partnership (PPP) or variant thereof such as Design Build Operate and Maintain is used, then at what point is a cost overrun determined? (Liu *et al*., 2016). The use of PPPs requires a scope to be completed prior to construction and provides a mechanism for trade-offs between construction and maintenance to be undertaken. In comparison to traditional forms of procurement, PPPs can reduce project costs, though their use for 'large' rail projects has been limited in Australia as there has been a preference to use alliance based contracts (Wood and Duffield, 2009; Terrill and Danks, 2016).

A comprehensive review of the factors influencing the variability between an initial forecasted budget and final tender sum has been provided in Adafin *et al*. (2016a,b) and includes: changes in owner/stakeholder requirements, planning requirements or restrictions, market conditions (e.g., fluctuations in labor prices), poorly prepared documentation, availability of design information and government legislation/policy. Issues, however, that have been eschewed by Adafin *et al*. (2016a) are optimism bias and strategic misrepresentation, which may be used to influence the budget estimate and its subsequent management during the design development process. As noted above, to determine how the aforementioned issues influence the costs up to the point where a contract is signed prior to the commencement of construction is highly subjective.

Irrespective of the point that is used to determine the cost overrun that is experienced, there remains a general consensus that rail projects, globally, are typically confronted by unnecessary expenditure increases. In Australia, for example, State Governments and their transport infrastructure deliver agencies have been criticized by the media (e.g. Moore 2016), lobby groups (e.g., Eco-Transit, 2015) and State Auditors (e.g., NSW Audit Office 2010; VAGO, 2010) over the escalating cost of rail projects. According to Martin (2011) State Governments need to acquire improved knowledge about the costs of their rail projects so as to develop more robust and reliable business cases. An analysis of 26 major public rail projects delivered in Australia between 2000 and 2009 revealed significant differences in construct costs per km (Martin, 2011): for example, the 12 kilometer (km) Epping Chatswood Railway line in Sydney (heavy suburban line) was the most expensive at AU$193.36 million per km, whereas the 72km Perth-Mandurah Line (heavy suburban line) was a fraction of the cost, at a mere AU$17.36 million per km. The cost difference between these two projects, for example, has engendered a perception that rail costs are higher than they should be in cities such as Sydney and Melbourne (Gatenby, 2009; Martin, 2011).

Research Approach

The research undertaken by Flyvbjerg (2007) and Canteralli *et al*. (2012a,b,c) was reliant on an ‘international database’, but limited information is provided about ‘what’ and ‘how’ their data was collated and why there was a reliance upon secondary sources. More specifically, the reliability of the data presented in Canteralli *et al*. (2012c) comes into question as they state "if the actual costs are unknown at the time of project completion, the most reliable later figure for actual costs is used (i.e. from a year later than the opening) if available. If unavailable, an earlier figure for actual costs could be used (i.e. from a year before the opening year), but only if 90% of the budget was spent at this time i.e. the project was 90% complete in financial" (p.326). In this instance, why and how was 90% determined? Notably, the percentage of projects that were deemed 90% complete are not presented by Canteralli *et al*. (2012c). Furthermore, Canteralli *et al*. (2012c) make a comparison with Flyvbjerg *et al*.'s (2002) original dataset of 258 projects, which was collected from projects completed at different time points and from an array of countries. The construction techniques, technologies, legal jurisdictions, political and economic environments, client types and procurement arrangements also differed, yet these limitations were overlooked (Love *et al*., 2015a).

The research presented in this paper sought to address these limitations and therefore used a case study approach to obtain data from a contractor who had extensive experience with constructing rail projects. A contractor who the researchers had collaborated with on several other studies was approached and their involvement in the study was solicited and subsequently obtained. Due to the paucity of empirical research and a lack of reliable primary cost data, an exploratory case study approach was undertaken to ameliorate understanding about the cost performance of rail projects (Shields and Rangarjan, 2013).

The contractor made available the rail projects that had been constructed between 2011 and 2014. The researchers were provided with access to each project's cost information, which were stored in a consolidated database. Projects that had commenced in 2015 and were in progress in 2016 were excluded from the research. Due to the commercial sensitivity of the data provided, only a brief description of each project is provided. Table 1 provides information about the type of project, the procurement methods used, the classification, location, original contract value, the cost change and the amount of scope changes that were incurred. While public and private sector asset owners sanctioning the identified projects were different, the contractor's processes (e.g., quality assurance systems, safety management and contract administrative procedures), technologies, and construction methods were standardized. In addition, it can be seen that the procurement methods used are also very similar, though this is often reflective of the business case that is established, the risk and complexity of the projects and prevailing economic conditions (Love *et al*., 2012b).

Analysis

A number of risk management tools can be used to determine an appropriate construction cost contingency, which include expert judgment, Monte Carlo simulation and Reference Class Forecasting (Love *et al*., 2015b; Terrill and Danks, 2016). There is 'no best' method to determine risk, but the approach that is selected needs to be reliable (i.e. uses objective information to counter optimism bias and strategic misrepresentation) and comprehensive (i.e. accounts for known, unknown, and known risks) (Terrill and Danks, 2016: p.49).

During the design process there is a tendency to undertake detailed risk assessments (e.g., conduct Monte Carlo simulations) and then simply apply a standard up-lift rate (deterministically) at contract award for a construction contingency (Love *et al*., 2015b). Yet evidence suggests that the up-lift figure that is applied is rarely sufficient to cover the additional costs that are incurred during construction (Baccarini and Love, 2014). Having access to the distribution of costs impacting a project's performance can enable both asset owners and contractors to 'anticipate what might go wrong'. This can therefore enable mechanisms to be put in place to ensure a project meets its expected deliverables. State Governments such as Queensland's Department of Main Roads (2015) and Infrastructure Australia (2016) have advocated the use of a probabilistic approach as part of a project risk management strategy. Thus, in accordance with practice, a Probability Density Function (PDF) was computed for a continuous distribution so that the likelihood for rail projects experiencing a cost overrun could be predicted. Descriptive statistics such as the mean (M), standard deviation (SD), and inter-quartile were also calculated for the 16 rail projects constructed by the contracting organization.

The PDF for a continuous distribution can be expressed in terms of an integral between two points:

$$P = \int_a^b f(x)dx \quad a \leq x \leq b$$ [Eq. 1]

A cumulative distribution functions (CDF) was also produced. For theoretical continuous distributions the CDF is expressed as a curve and denoted by:

$$F(x) = \int_{-\infty}^{x} f(t)dt$$ [Eq.2]

The empirical CDF, which is displayed as a stepped discontinuous line and dependent on the number of bins, is represented by:

$$F_n(x) = \frac{1}{n} \cdot [\text{Number of observations} \leq x]$$ [Eq.3]

The PDF, Cumulative Distribution Functions (CDF) and distribution parameters ($\alpha, \beta, \gamma, \mu, k, m, \sigma, \xi$) for continuous distributions such as *Beta*, *Burr*, *Cauchy*, *Error*, *Gumbel Max/Min*, *Johnson SB*, *Normal*, and *Wakeby* were examined using the estimation method Maximum Likelihood Estimates. The 'best fit' distribution was then determined using the following 'Goodness of Fit' tests, which measure the compatibility of a random sample with a theoretical probability distribution:

- *Anderson-Darling statistic (A^2)*: A general test to compare the fit of an observed CDF to an expected CDF. The test provides more weight to a distributions tails than the *Kolmogorov-Smirnov* test. The Anderson-Darling statistic is defined as:

$$A^2 = -n - \frac{1}{n}\sum_{i=1}^{n}(2i-1) \cdot \left[InF(x_i) + In\left(1 - F(x_{n-i+1})\right)\right]$$ [Eq.4]

- *Chi-squared statistic* (χ^2): Determines if a sample comes from a population with a specific distribution. The Chi-squared statistic is defined as:

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \qquad \text{[Eq.5]}$$

- *Kolmogorov-Smirnov statistic (D)*: Based on the largest vertical difference between the theoretical and empirical CDF:

$$D = \max_{1 \le i \le n} \left(F(x_i) - \frac{i-1}{n}, \frac{i}{n} - F(x_i) \right) \qquad \text{[Eq.6]}$$

where O_i is the observed frequency for bin *i*, and E_i is the expected frequency of bin *i* calculated by:

$$E_i = F(x_2) - F(x_1) \qquad \text{[Eq.7]}$$

Here *F* is the CDF of the probability distribution being tested, and x_1, x_2 the limits for the bin *i*.

The above 'Goodness of Fit' tests were used to test the null (H_o) and alternative hypotheses (H_1) of the datasets: H_0 - follow the specified distribution; and H_1 - do not follow the specified distribution. The hypothesis regarding the distributional form is rejected at the chosen significance level (α) if the statistic D, A^2, χ^2 is greater than the critical value. For the purposes of this research, a 0.05 significance level was used to evaluate the null hypothesis.

The *p*-value, in contrast to fixed α values is calculated based on the test statistic and denotes the threshold value of significance level in the sense that H_o will be accepted for all values of α less than the *p*-value. Once the 'best fit' distribution was identified, the probabilities for a cost change were calculated using the CDF. Then, to simulate the samples randomness and derive the probabilities of a cost overrun (e.g., scope changes in this case) arising during construction, a *Mersenne Twister*, which is pseudorandom number generating algorithm, was used to generate a sequence of numbers that approximated the sample to 5000 (Matsumoto and Nishimura, 1998).

Results

The total value of rail projects that had been originally awarded to the contractor between 2011 and 2014 was AU$539,569,997, with an M= AU$33,723,124 and SD=AU$78,398,023 (Table 1). The total value of work that was undertaken was AU$665,479,369, an increase of 19%. This additional increase was predominately due to client initiated scope changes. Two rail projects incurred cost increases other than the scope changes that were approved by their clients, namely an 'Urban Track Upgrade' and the 'Installation and Maintenance of Concrete Sleepers', which experienced non-conformances accounting for AU$397,978 and AU$115,560, respectively. Noteworthy, two projects experienced a cost underrun due to changes in scope. As it can be seen in Table 1, a variety of rail projects were undertaken such as 'New Build' (50%) and a combination of 'New Build and Upgrades' (25%) with most being constructed in Western Australia (WA) (63%).

A total of 10 (63%) rails projects were procured using a 'Traditional Lump Sum' method, with three (19%) by 'Traditional Cost-plus', two (13%) by 'Design and Construct' and one (6%) using an Alliance contract. The three projects that used a 'Traditional Cost-plus' were for a private sector client. The 'Alliance' project, which was the largest rail project undertaken by the contractor, was undertaken in Victoria and formed part of one of Australia's largest public infrastructure projects. The Victorian State Government often used an 'Alliance' procurement method as capital costs for this high risk complex projects due to it exceeding AU$50 million. The works included the laying of new tracks, the construction of new rail overpasses, modifications to existing bridges, extensive track reconfiguration and the upgrading of signaling systems.

The mean cost overrun from the contract award that was experienced for the 16 sampled projects was 23% (Table 2). Interestingly, two were delivered using a 'Traditional Lump' methods (13%) experienced cost underruns, with the remaining 50% incurring a mean cost overrun of 12.83%. The maximum cost overrun was 96.73% and the minimum was -4.19%. If the initial budget estimate (also referred as the 'Time of formal decision to build (ToD)) (Canteralli *et al*., 2012c) had been used as the point to determine the extent of the cost overrun, then there is no doubt that the figures presented would be significantly inflated. For the 'Iron Ore' project, which incurred a cost overrun of 96.73%, the original scope of works was AU$1,200,000 and increased to AU$36,691,000. The contractor, however, was initially required to undertake site preparation works, but as the mine owner was under pressure to commence operations and ship its iron ore to market, new works were added to the existing cost-plus contract (i.e. the contractor was paid for their expenses, which were to a set limit plus an additional payment for profit), which had already been established. If a new contract had been created, then a cost overrun would not have been registered.

Distribution Fitting: Probability of Cost Change

The 'best fit' probability distribution was determined using the following 'Goodness of Fit' tests (Love *et al*., 2015b): *Anderson-Darling, Chi-squared statistic and Kolmogorov-Smirnov,* The results of the 'Goodness of Fit' tests revealed that *Three Parameter (3P) Frechet* distribution provided the best fit for the dataset (Table 3).

< Insert Table 3. Goodness of Fit Tests for rail projects >

A Frechet is a form of generalized extreme value distribution (GEV) that is used as an approximation to model the maxima of long (finite) sequences of random variables (Coles, 2001). The PDF is expressed as:

$$f(x) = \frac{\alpha}{\beta}\left(\frac{\beta}{x-\gamma}\right)^{\alpha+1} \exp\left(-\left(\frac{\beta}{x-\gamma}\right)^{\alpha}\right) \qquad \text{[Eq.8]}$$

The CDF is expressed as:

$$f(x) = \exp\left(\left(-\frac{\beta}{x-\gamma}\right)^{\alpha}\right) \qquad \text{[Eq.9]}$$

α is a continuous shape parameter with $\alpha > 0$ $\beta > 0$ and γ is a continuous location parameter where $\gamma \equiv 0$ yields the two parameter-Frechet distribution. The domain for the 3P Frechet distribution is $\gamma < x < +\infty$.

The parameters for the *Frechet (3P)* were found to be α = 2.496, β = 31.459 and γ = -22.568. Figures 2 and 3 present the PDF and CDF based upon the calculated distribution parameters. The calculated probabilities, based upon 3rd quantile (75%), a cost overrun being experienced are presented in Table 4. The probability of experiencing a cost change of >10% is 32%. Delimiters have also been used to provide probabilities of cost changes within ranges. The probability of a project experiencing between a 15% and 25% cost change, for example, is 17% (Figure 4). For a mean cost overrun of 23% to be experienced the likelihood of occurrence is 60% (P (x < x1) = .67) from contract award. Explicitly, the construction cost contingency for 14 of the sampled projects was unable to accommodate the scope changes that were needed for them to serve their intended purpose. At contract award, Clark and Lorenzoni (1985) have suggested using an up-lift contingency value of 3% to 5% of a project's contract value to accommodate unresolved design issues; in the case of the rail projects sampled, the use of a deterministic approach is clearly does not accommodate the percentage increase in costs that were incurred.

Discussion

Delivering rail projects within their forecasted construction cost is a priority for public and private sector organizations. The analysis demonstrates the likelihood of rail projects exceeding a 20% overrun is high based on current practices. In an attempt to ensure cost certainty in rails projects, procurement methods such as 'Traditional Lump Sum', 'Design and Construct' and 'Alliances' are often employed. In the case of a 'Traditional Lump Sum' method, the public sector generally accepts that design work will generally be separate from construction.

Consultants are appointed for design and cost control only, and the contractor is responsible for carrying out the works for a fixed sum. This responsibility extends to all workmanship and materials, and includes all work by subcontractors and suppliers. The contractor is usually appointed by competitive tendering on complete information, but may if necessary, be selected earlier by negotiation on the basis of partial or notional documentation and undertakes to carry out a defined amount of work in return for an agreed sum.
According to Love *et al*. (2012b) the concept of cost certainty is a fallacy when using traditional methods that are based upon full drawings and bills of quantities (BoQ). In principle this approach should provide the public and private sector asset owners with a firm, fixed price for construction, but in practice very few projects are actually completed within their tendered price (Rowlinson, 1999); this was clearly evident in the rails projects that were examined. Complete drawings and BoQs are generally unavailable when a projects goes to tender and the documentation and often contains errors and omissions, which may result in scope changes and rework being made undertaken during construction (Love *et al*., 2012a).

With 'Design and Construct' methods, a contractor accepts responsibility for some or all of the design. Design and construct methods offer certainty on the contract sum with the provision of a GMP and bring cost benefits. The close integration of design and construction methods and the relative freedom of the contractor to use their purchasing power and market knowledge most effectively, can provide the public and private sector with a competitive price. However, changes in scope can be costly. Considering the inherent degree of cost certainty that this form of procurement method can provide, it was surprising to find that costs were incurred, but both projects in question were constructed in an urban environment; a close examination of the scope changes revealed that additional work was required to relocate underground utilities. Similarly, the scope changes approved by the public authority generally related to unexpected signaling issues and integrating newly installed communication systems with an existing mainline station power distribution network.

It has been widely acknowledged that collaborative procurement method such as 'Alliances' and 'Design and Construct' and PPPs can provide improved cost performance and value-for-money for the public sector (e.g. Muriro and Wood, 2010). In fact, as noted above, PPPs have been demonstrated superior cost-efficiency over traditional methods ranging from 30.8% (from project inception) to 11.4% (from contractual commitment to final outcome) (Infrastructure Partnerships Australia, 2008). Despite the cost benefits that have been found to materialize from the use PPPs, they have also received widespread criticism, particularly with dealing with risk transfers over an assets life (e.g. Hodge, 2004). The Latham (1994) and Egan Reports published in the UK (1998) served as a catalyst for reforming the construction industry so that the performance of projects would improve. Moving forward 20 years and it can be observed that the level of cost overruns occurring has not diminished; a conclusion also propagated by Flyvbjerg *et al*. (2003). Cost overruns, however, will remain a pervasive problem unless fundamental changes are made to the way in which projects are governed, procured (e.g., collaborative relationship contracting, and bundling) and technological innovations are embraced, so as to improve the cost performance and management of information throughout an assets life-cycle (Love *et al*., 2015a).

Improving Cost Estimation

Following the strategic justification phase, which examines what is required to meet the demands and needs of the public and business community rail needs, an initial budget estimate is prepared. Typically, the initial estimate increases as the project progresses through the design development process. Having to constantly revise and amend the initial budget can be disruptive and may result in shortfalls in public funding occurring (Department of Transport and Main Roads, 2015). The performance of an initial budget estimate can only be assessed when a project is completed. Thus, the initial budget estimate needs to contain sufficient design contingency to accommodate changes to a projects scope. It is during this stage that those responsible for preparing the initial budget estimate may succumb to optimism bias.

To ensure the reliability of the initial budget estimate and contingency, external professionals' advice and evaluation, particularly cost consultants (e.g., quantity surveyors), should be sought. In-line with contemporary procurement thinking (e.g., Loosemore, 2016), it is suggested that there needs to be shift-away from traditional to relational methods and therefore involve contractors in vetting initial budgets. Indeed, this can be considered to be a controversial idea as questions associated probity may arise. Nevertheless, the aim here would be to remove ‘uncertainties’ and identify to potential risks that may materialize; the inclusion of contractor’s early input in the design process would improve a project’s constructability and provide a platform engendering collaboration between parties. When contractors assess the initial budget they could also be invited to identify innovative methods of construction; it is suggested that any advice provided would be fee-based and issues associated with intellectual property would need to be resolved, if they were not awarded a contract to deliver the works. Naturally, as a project moves through its various stages of development key decision-makers and policy advisors need to sign-off and approve the estimate as its evolves.

At the initial budget stage, it has been suggested that a contingency of 30% to 50% should be allowed for incomplete scope and 5% to 10% for estimating inaccuracies (Clark and Lorenzoni, 1985). Therefore, as a rule of thumb, a 35% to 60% design contingency should be added to the initial budget estimate figure. For example, the Department of Transport and Main Roads (2015), for example, there is an expectation that initial budget estimates have a 90% confidence factor (P90) of not being exceeded at completion. Producing an estimate with such a high confidence factor is dependent upon having access to good quality information (e.g., costs from previous projects, specific requirements of stakeholders, procurement options, and market conditions). A series of cost scenarios that can materialize in projects are presented in Figures 5 to 7. The ideal scenario is one where the budget estimate that is established excluding the contingency equals the final cost. This is an unlikely scenario considering the existing practices and processes that are used to design and construction rail projects and the limited understanding of the systemicity and interdependency of risk (Love *et al*., 2016a).

< Figure 5. The ideal cost scenario >

< Insert Figure 6. An acceptable cost scenario >

< Insert Figure 7. Unacceptable cost scenario >

In the projects sampled, an unusually high proportion of the cost overruns were due to scope changes. The nature of these changes could not be quantified within the sample of projects that were analyzed due to their commercial sensitivity, but considering previous empirical research that has been undertaken, they were likely to be attributable due to client initiated design changes, errors or omissions contained within the design documentation (Love *et al*., 2004). For the rail projects presented in this research, the probability of scope changes is established based on existing practices to document and management information, which was undertaken using the medium of Computer-Aided-Design (CAD) by independent design and engineering disciplines.

Improving Information Quality

An unacceptable cost scenario, which may well have arisen within the rail projects procured *via* 'Cost-plus' methods, can be seen in Figure 7. In such situations there is an overwhelming precedence to ensure that the rail asset operates as soon as possible, and as a result of this urgency its scope becomes poorly defined. To reduce the scope changes, and improve the quality of information that is made available for purposes of decision-making throughout a rail assets life, technological and process innovations such as Building Information Modelling (BIM) (Figure 8) and Systems Information Modelling (SIM) (Figure 9) should be implemented simultaneously (Love *et al*., 2016b,c).

The US National Building Information Model Standard Project Committee (2015) has defined BIM as "a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle, which is defined as existing from earliest conception to demolition". A SIM, however, is a derivative of BIM, but 'Building' is replaced with 'System' to represent the process of modeling complex connected systems, such as electrical control, power and communications (herein after electrical systems), which do not possess geometry (Love *et al*., 2016b,c). Essentially, a SIM takes a discipline specific perspective, but can be integrated within a BIM when a single point of truth is formed.

When a SIM is applied to engineer and document a system, all the physical equipment and associated connections, similarly to constructing a building information model, are modeled in a relational database with each component modeled only once resulting in a 1:1 relationship between the SIM and the real world. However, when using CAD, which has been and remains the preferred method to document the design of electrical systems within the rail sector, each object in the real world may appear on multiple drawings and each drawing may contain a number of objects. Thus, an n:n relationship is formed between the real-world objects and the drawings, and propensity for errors and omissions to materialize significantly increases as changes to individual CAD drawings need to be undertaken and up-dated manually.

< Insert Figure 8. Extracts from a building information model for a rail project>

< Insert Figure 9. Creation of a retrospective SIM from a rail project >

When BIM is used to establish an initial budget estimate, its visualization capacity can be used to explore design solutions and develop a preliminary construction program, undertake life-cycle costing, functional analysis and cost benchmarking. From the on-set stakeholders can visualize the rail asset, which can enable critiques and modifications to be made while instantaneously being able to determine the impact on the project's cost, particularly during construction. As the design and engineering mature, costs can be monitored and alternative options analyzed. With the early involvement of a contractor, for example, the potential of optimism bias can be significantly diminished as 'checks and balances', as well as costs that reflect actual market prices can be considered and brought to the fore.

Early contractor involvement may not always be feasible and practical, and will invariably depend upon the value of the project. However, this does not discount the influence that the independent design team can have in using BIM to ensure the constructability and the cost effectiveness of various options that may be put forward for consideration. For example, in Figure 8, a number of scenarios that can be modelled and examined in a BIM environment for a rail project are presented: a tunnel's alignment can be modelled juxtaposed with Geographical Information Systems, track schedule progress can be tracked and visualized (4D), and cost and schedule progress of stations can be monitored in real-time as construction is being undertaken (5D).

Working within a BIM environment will significantly reduce scope changes and thus provide greater cost certainty (Hartman *et al*., 2012). It is therefore anticipated that when BIM is applied to rail projects the probability of cost overruns being incurred will dramatically reduce. To achieve the real benefits of a BIM solution requires collaboration between all parties who are selected to deliver a rail asset, particularly when there is a requirement to produce a building information model is utilized during Operations and Maintenance (O&M). London's £14.8 billion Crossrail network project has been applying BIM to help planners integrate new train lines into existing infrastructure (Peplow, 2016). According to Peplow (2016) the use of BIM has saved time and money by reducing construction errors, which often manifest as additional costs as scope changes or rework. The use of clash detection, laser scanning, compliance checking, sensors to check and monitor the integrity of the rail network, have all contributed to ensure mitigating scope changes and rework in Crossrail, and as a result have contributed to ensuring the assets integrity for O&M.

Rail projects are dependent on electrical systems to function. Like BIM, a SIM can be used to establish the initial budget estimate for such systems and provide approximate quantities as cable lengths, connectors and devices can be determined when the route for the project has been established. Empirical research has demonstrated that the use of a SIM during design can provide as much as a 90% reduction in the amount time and cost to prepare documentation (Love *et al*., 2013). In addition, a SIM significantly reduces the propensity for errors and omissions to be made as well as information redundancy in documentation thereby minimizing the proclivity of scope changes during construction.

Being able to provide information in a format that does not possess 'noise' is an essential ingredient in developing an initial budget estimate for electrical systems. Rail projects often require up-grades to tracks and maintenance and estimating the cost of such projects requires an understanding of not only the new work to be undertaken but also the existing network. Using 3D laser scanning, high-resolution imagery from linear and real world positions, an existing network can be integrated with the new design and its costs appropriately determined (Figure 8).

Limitations

Akin to Flyvbjerg (2007) and Canteralli *et al*. (2012c), this research presented has limitations. The most notable is the sample size, which was limited to 16, though a Mersenne Twister, was used to generate a sequence of pseudorandom numbers that approximated the sample to 5000. The data, however, is homogenous, reliable and is reflective of 'actual' costs that were incurred. While the projects were diverse in their geographical location, they are not representative of Australia; the Australian Capital Territory (ACT), Northern Territory (NT), Queensland (QLD) and Tasmania are not represented. This is important considering that in New South Wales and Victoria have been identified as experiencing higher construction costs for rail than other States and Territories.

Unfortunately, the findings could not be compared with Flyvbjerg (2007) and Canterralli *et al*. (2012c) as procurement methods, construction costs, scope changes incurred, and economic conditions were not presented. In addition, Flyvbjerg (2007) focused upon 'mega' projects, which are unique and thus are unable to be compared to the general works programs undertaken by State Governments and asset owners. The economic climate within which projects were undertaken between 2011 and 2014 was significantly different between Australia States and the ACT and when Flyvbjerg (2007) and Canterralli *et al*. (2012c) conducted their studies. For example, WA (also NT and QLD, though projects were constructed by the contractor from 2011 to 2014) was experiencing an economic boom and significant increases in population growth due to a demand for energy mineral resources, while other States and the ACT were experiencing significantly reduced levels economic activity.

Conclusions

The cost performance of rail infrastructure projects has received considerable attention as they are seldom delivered within budget, particularly those classified as being 'mega' projects. As a result, research has tended to place emphasis on projects of that are of the 'mega' magnitude and provide additional explanations as to 'why' and 'how' cost increases arise. The justifications put forward for those being classified as being 'mega' while plausible are divorced from the actual data that has been presented, even the solutions for improving the accuracy of budget estimates do not reflect the complexity, systemicity and interdependency of risk that can arise during the delivery of rail projects.

Recognizing these shortcomings, this paper examines the cost performance of a sample of 16 rail projects that were constructed by a single contractor. Cost performance for the rail projects was calculated from the contract award until final completion, which has been in stark contrast to planning and transport literature that has focused on using the initial budget estimate or the decision to build as the reference point for its determination. Consequently, the determination of cost performance from contract award provides a realistic measure of the overrun/underrun that materializes as a degree of certainty is assured to the asset owner as an agreed sum for the works to be completed is established.

The analysis revealed that a mean cost overrun of 23% of the original contract value, with 99% of the total cost increase incurred being due to scope changes. Considering prevailing practice, the probability of cost overruns arising where determined so that adequate contingency could be established in the future. It appears, however, that the magnitude of cost increases being experienced in rail projects are not decreasing and the problem remains the same as of fifty years ago or more.

In addressing this problem, changes in the way that the initial budget estimate and its development needs to be undertaken by the public and private sector asset owners of rail infrastructure, which include:

- the determination of contingencies based upon probabilistic methods such as distribution fitting identified and demonstrated in this research, particularly for construction;
- the greater use of collaborative procurement methods such as Alliances, which includes financial incentives so as to ensure a guaranteed maximum prices;
- third party audit of the initial budget by external consultants to minimize the potential for optimism bias;
- involvement of contractors, particularly those specializing in electrical systems early in the design process to provide constructability advice with particular emphasis being placed on the evaluation of initial budget estimate; and

- the use of Building Information Modelling (BIM) and Systems Information Modelling (SIM), which can be used to mitigate scope changes and thereby reduce the size of the contingency that is required for construction.

The cost overrun phenomena is a complex and challenging problem to address. This paper does not attempt to provide answers, but a way forward in dealing with this issue. There is a need, however, to better determine construction cost contingencies; but the use of collaborative forms of procurement juxtaposed with the use of BIM and SIM will provide the public and private sector asset owners charged with delivering and maintaining rail networks with confidence that projects can be delivered cost effectively and are resilient to unexpected events and adaptable to changing needs, uses or capacities.

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Table 1. Cost information for rails projects constructed between 2011 and 2014 by geographical region (n=16)

Project Type	**Procurement Method**	**Classification**	**State**	**Original Contract Value ($)**	**Final Contract Value ($)**	**Cost Difference**	**% Cost Change**	**Scope Changes ($)**
Installation and Maintenance of Concrete Sleepers	Traditional Lump Sum	Up-grade and Maintenance	Western Australia	12,905,657	12,386,515	-519,141	-4.19	-403,581
Track Extension and Installation of a Crossing	Traditional Lump Sum	New Build	Western Australia	3,480,286	3,418,423	-61,863	-1.81	-61,863
Modification and Upgrade of Track	Traditional Lump Sum	New Build and Up-grade	Western Australia	5,404,773	6,382,221	977,448	15.32	977,448
Iron Ore Track Extension (Spur Line)	Traditional Lump Sum	New Build	Western Australia	3,293,777	3,715,808	422,030	11.36	422,030
Track Maintenance	Traditional Lump Sum	Maintenance	New South Wales	15,816,417	17,040,378	1,223,961	7.18	1,223,961
Track Inspection and Maintenance Depot	Traditional Lump Sum	New Build	New South Wales	2,687,086	3,585,429	898,343	25.05	898,343
New Trackwork	Traditional Lump Sum	New Build	Western Australia	2,501,453	3,341,107	839,653	25.13	839,653
Urban Light Rail	Design and Construct	New Build	New South Wales	81,519,436	106,472,525	24,953,089	23.44	24,953,089
New Signals	Traditional Lump Sum	Up-grade	South Australia	8,942,956	9,761,790	81,8834	8.39	81,8834
Urban Rail Revitalization - Electrification	Design and Construct	Electrification	South Australia	15,037,635	17,333,340	2,295,705	13.24	2,295,705
Regional Rail (Includes new track and station, bridge refurbishment)	Alliance Contract	New Build and Upgrade	Victoria	318,307,311	353,376,242	35,068,931	9.92	35,068,931
Urban Rail (Track Extension)	Traditional Lump Sum	New Build	Western Australia	23,959,264	25,385,033	1,425,769	5.62	1,027,891
Freight Track	Traditional Cost-Plus	New Build	Western Australia	12,748,006	28,369,461	15,621,455	**55.06**	15,621,455
Urban Track Upgrade	Traditional Lump Sum	New Build and Upgrade	Western Australia	29,914,480	31,352,254	1,437,774	4.59	1,437,774
Iron Ore Track Extension (Spur Line)	Traditional Cost-Plus	New Build and Upgrade	Western Australia	1,851,459	6,867,640	5,016,181	**73.04**	5,016,181
Iron Ore New Build	Traditional Cost-Plus	New Build	Western Australia	1,200,000	36,691,197	35,491,197	**96.73**	35,491,197

Table 1: Descriptive statistics for cost change

Statistic	**Value (%)**
Range	100.92
Mean	23.00
Variance	793.15
Std. Deviation	28.16
Coef. of Variation	1.22
Std.Error	7.04
Skewness	1.70
Excess Kurtosis	2.33
Min	-4.19
5%	-4.19
10%	-2.52
25% (Quartile 1)	6.01
50% (Median)	12.3
75% (Quartile 3)	25.11
90%	80.14
95%	96.73
Max	96.73

Table 3. Goodness of Fit Tests

Distribution Type	**Sig. α Level**	**Kolmogorov-Smirnov (*D*) Critical Value**	**Anderson Darling (A^2) Critical Value**	**Chi-squared (χ^2) Critical Value**
Frechet 3P (Rail Projects)	**0.2**	0.25778	1.3749	1.6424
	0.1	0.29472	1.9286	2.7055
	0.05	0.32733	2.5018	3.8415
	0.02	0.36571	3.2892	5.4119
	0.01	0.39201	3.9074	6.6349

Table 4. Examples of probabilities of cost overrun

Probability Cost Overrun	**P(X < X1)**	**P(X > X1)**	**P(X1< X < X2)**	**P(X < X2)**	**P(X >X2)**
1 and 5%	0.13	0.87	0.12	0.25	0.75
6 and 10%	0.28	0.72	0.12	0.40	0.60
11 and 15%	0.43	0.57	0.09	0.53	0.47
16 and 20%	055	0.45	0.08	0.62	0.38
21 and 25%	0.64	0.36	0.06	0.70	0.30
26 and 30%	0.71	0.29	0.04	0.75	0.25

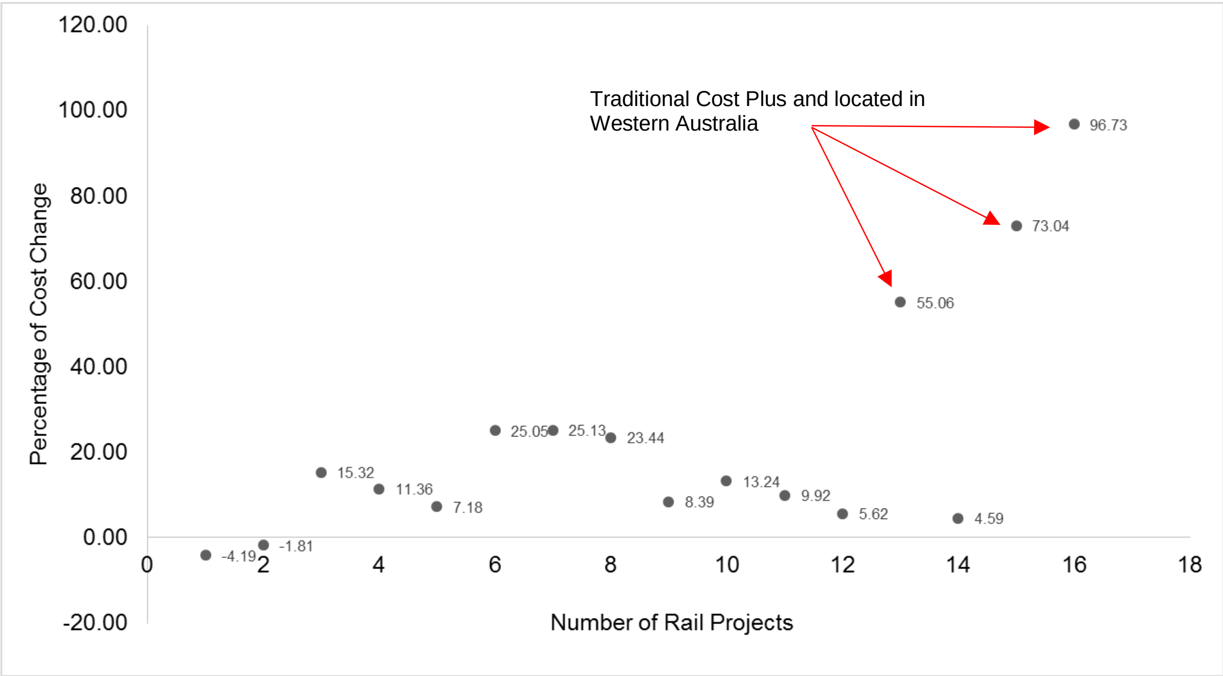


Figure 2. Scatterplot of rail projects

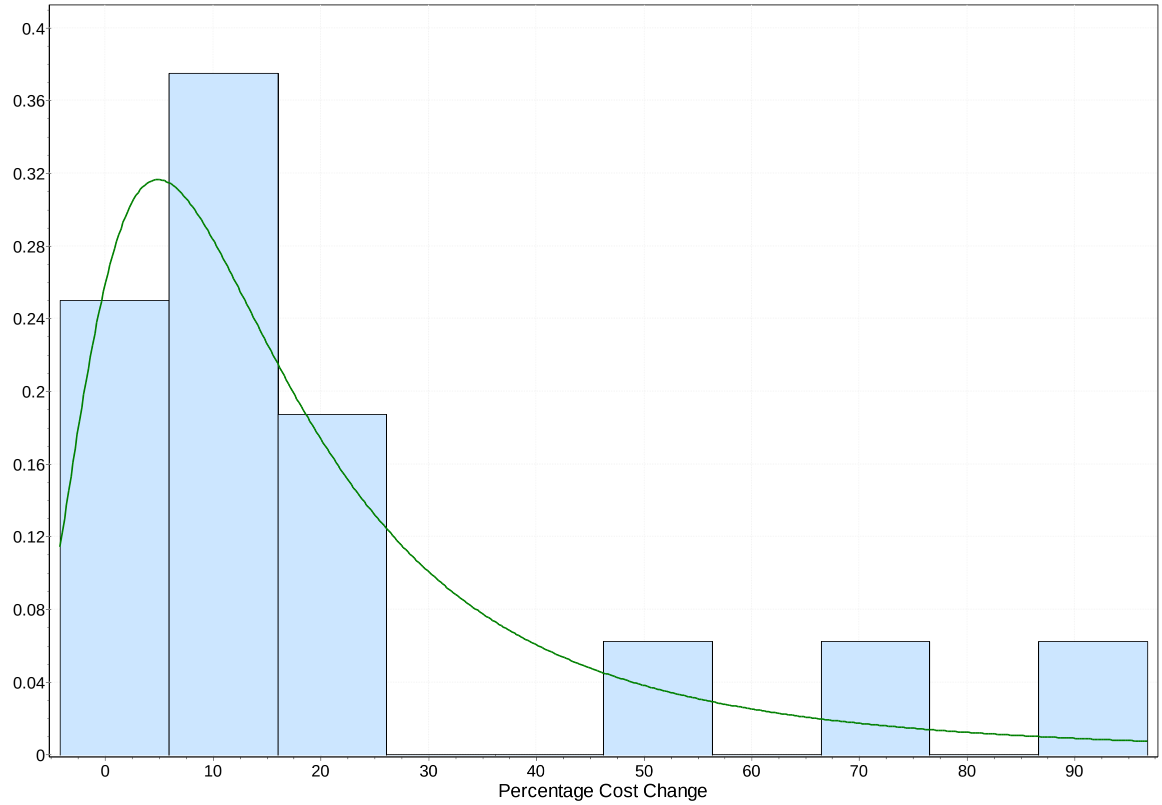


Figure 2. Frechet 3P: PDF for cost change

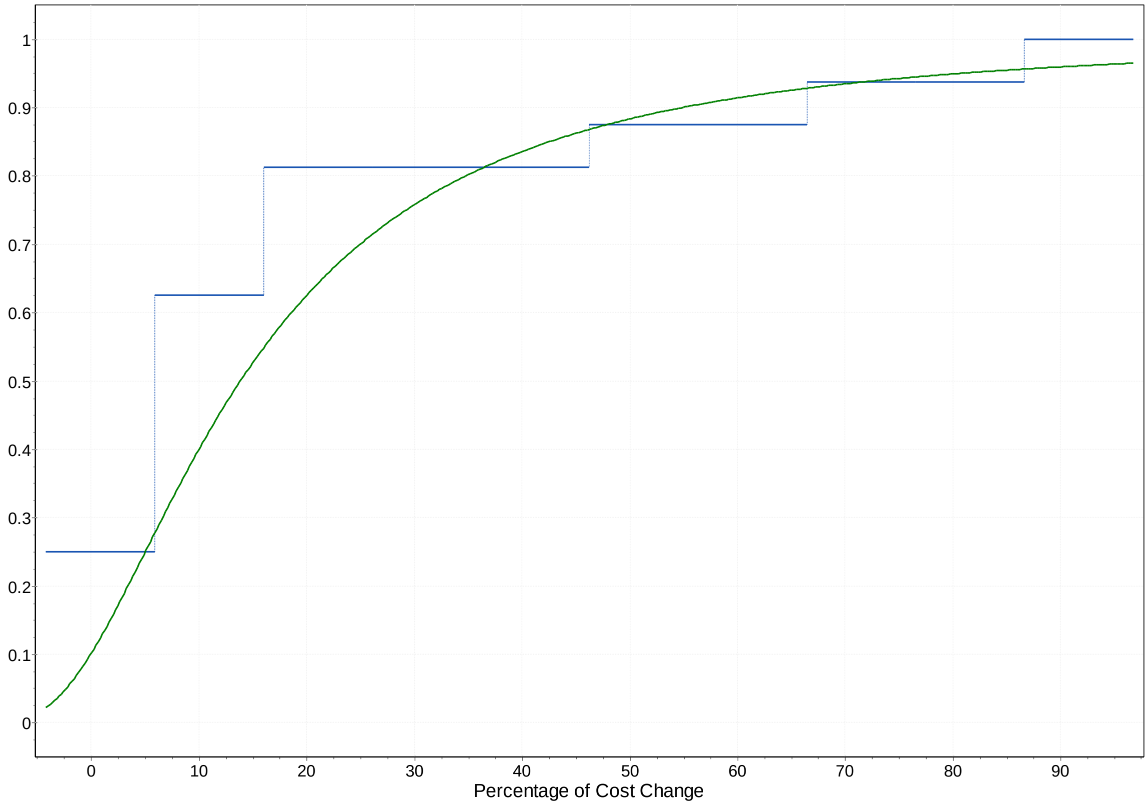


Figure 3. Frechet 3P: CDF for cost change

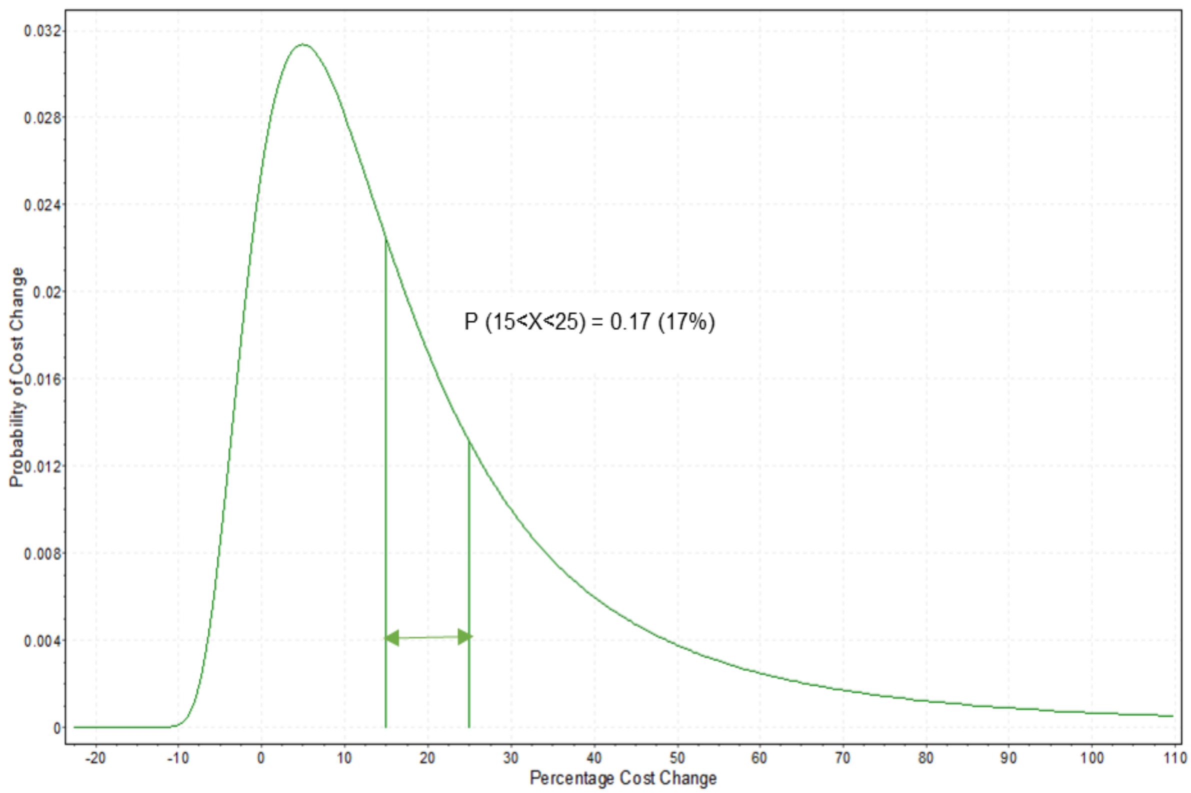
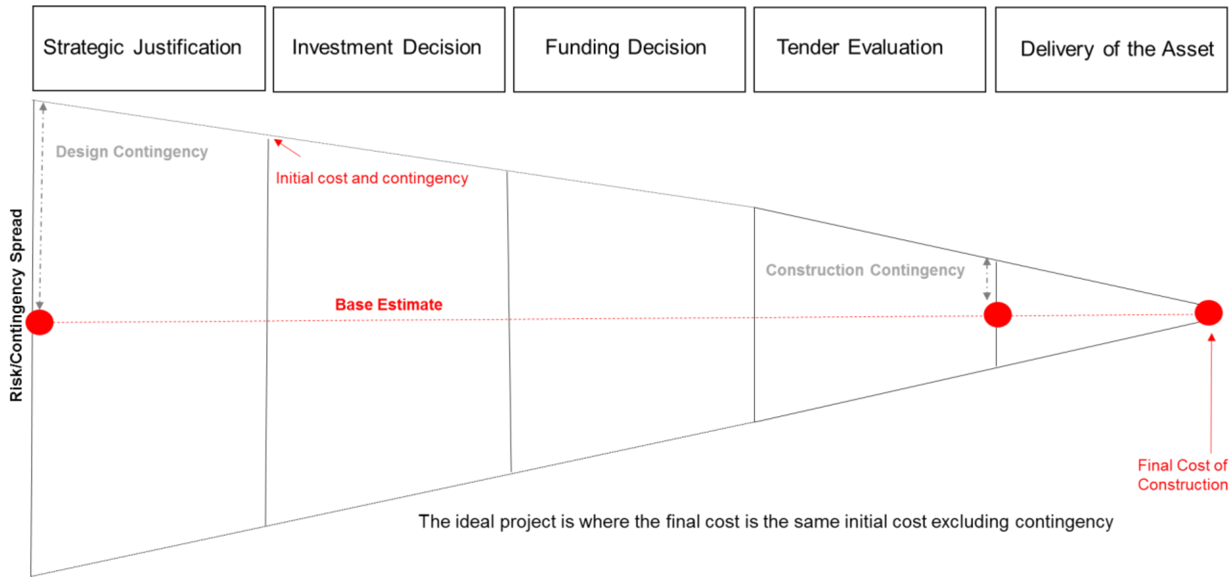
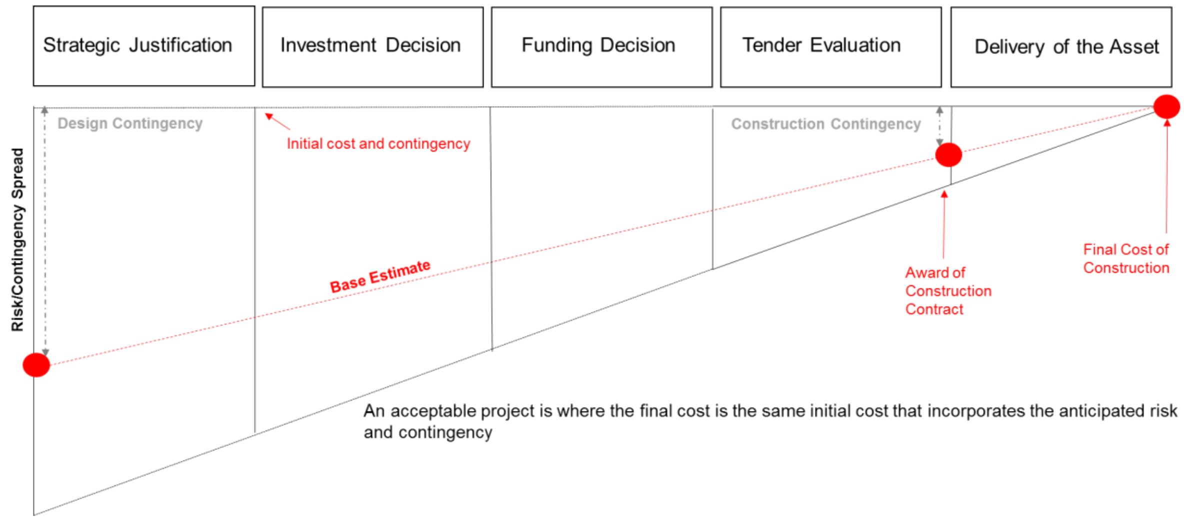


Figure 4. PDF with delimiters between 15% and 25% cost change



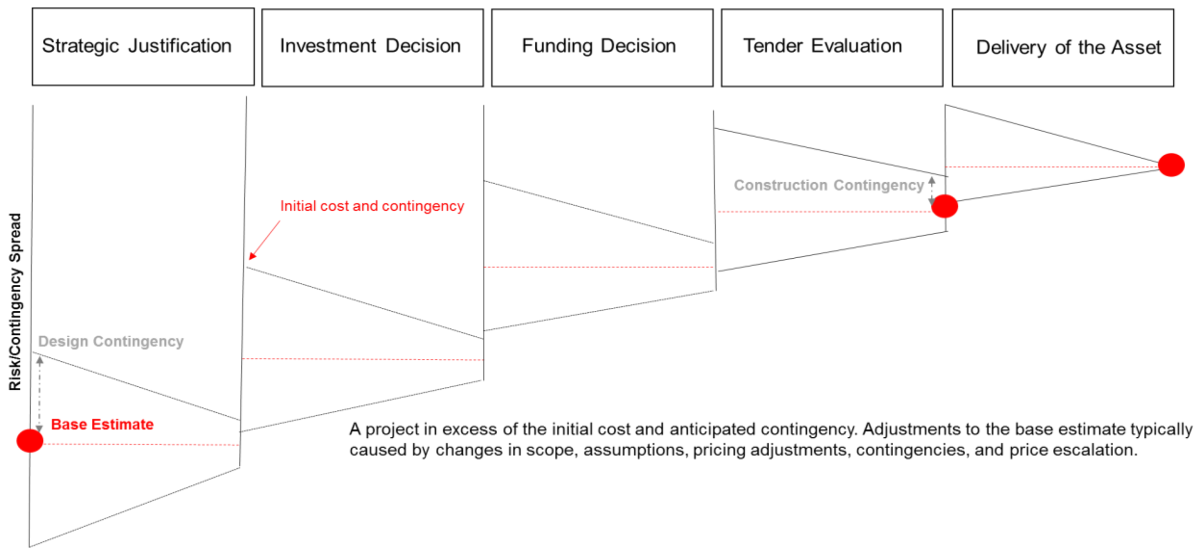
Adapted from: Department of Transport and Main Roads (2015:p.4)

Figure 5. The ideal cost scenario



Adapted from: Department of Transport and Main Roads (2015:p.5)

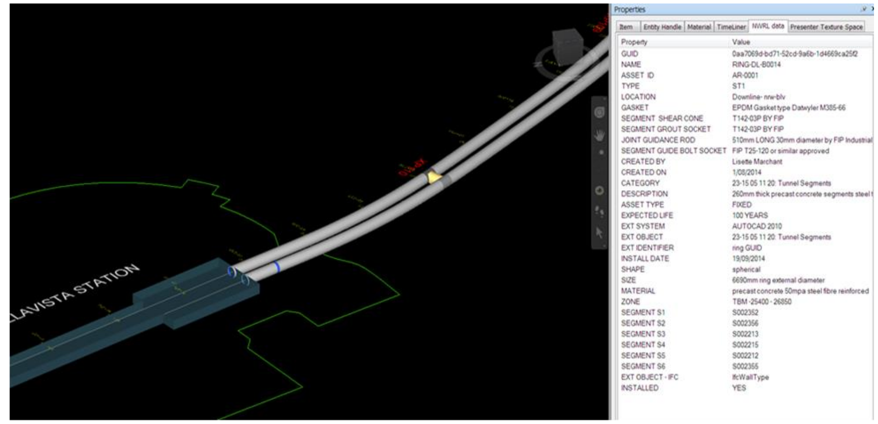
Figure 6. An acceptable cost scenario



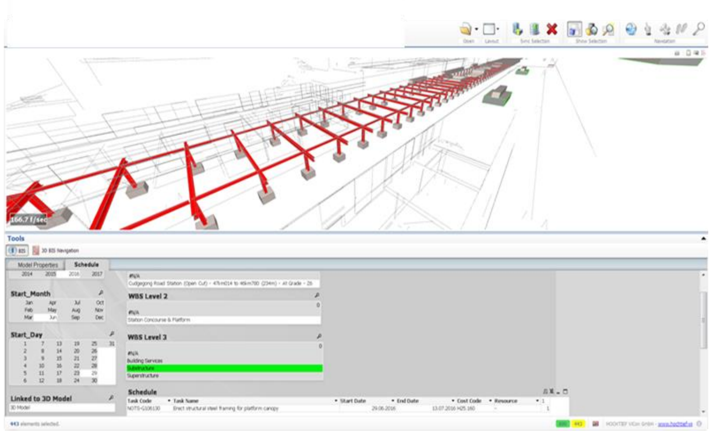
Adapted from: Department of Transport and Main Roads (2015:p.5)

Figure 7. Unacceptable cost scenario

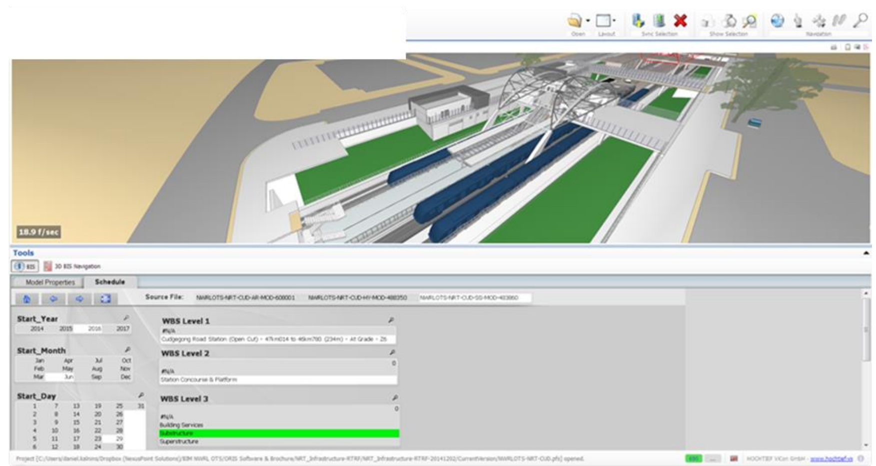
a. Realistic view of a rail tunnel



b. Tunnel Boring Machine using Geographical Information Systems



c. 4D Schedule progress of track progress



d. 5D progress of schedule and cost of a Station

Figure 8. Extracts from a Building Information Model for a rail project

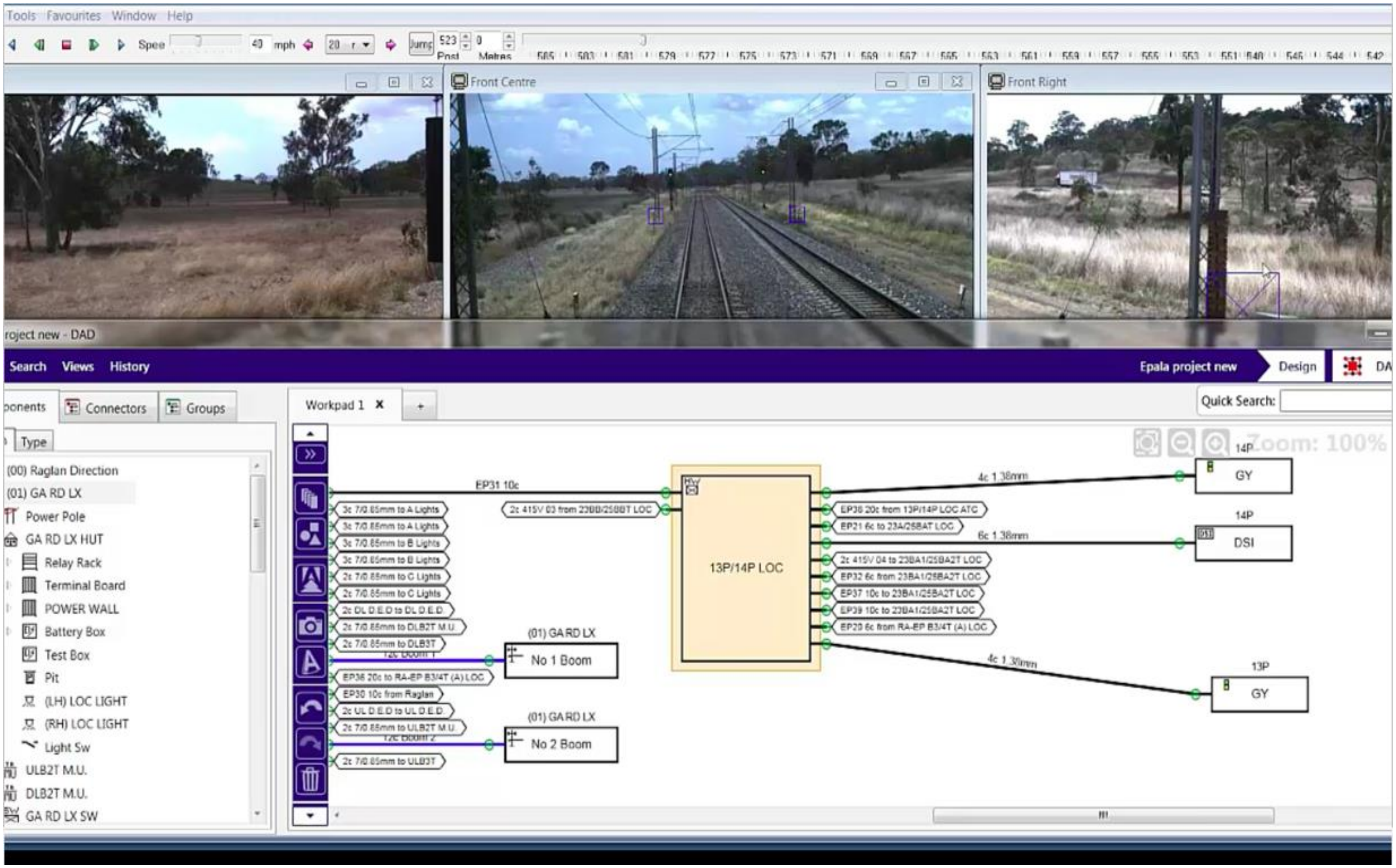


Figure 9. Creation of a Systems Information Model for a rail project